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Procedia Engineering 32 (2012) 544 – 549
Procedia Engineering
www.elsevier.com/locate/procedia

I-SEEC2011

Design of Frequency Doubler Using Inductively Compensated Microstrip Ring Resonator

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Elsevier use only: Received 30 September 2011; Revised 10 November 2011; Accepted 25 November 2011.

Abstract

This paper presents a simple design technique of resistive frequency doubler by using a microstrip square ring resonator based on inductively compensated parallel-coupled lines as an output stage. The proposed topology with simple design equations is demonstrated with the input and output frequencies of 0.9/1.8GHz and less than 3.2 dB insertion losses. More than 26 and 22 dB of spurious suppression performance at the 2nd and 3rd harmonics frequencies are obtained from the experimental results. The capability of the proposed square ring resonator was demonstrated by employing as the output stage of the resistive frequency doubler to enhance the suppression performance of circuit. The measured result of 0.9/1.8 GHz input and output signal frequency doublers is shown with the exhibit more than 40 dB suppression at frequencies f_0 and $3f_0$ below the desired frequency $2f_0$ and the conversion loss is less than 12.6 decibel.

Keywords: Square Ring Resonator; Parallel-coupled lines; Inductive compensation and miniaturization technique; spurious suppression; resistive frequency doubler

1. Introduction

Microstrip ring resonators have many applications in microwave and millimeter-wave systems, such as filters, oscillators, antennas, and frequency-selective surfaces devices. The theory of ring resonators on these various applications are well documented [1-4]. In the practical point of views, the utility of ring resonators was limited by the rejection bandwidth, which is determined by the occurrence of multiple modes [5]. Filtering of the ring resonator in either before or after can be used if the certain modes are

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doi:10.1016/j.proeng.2012.01.1306

undesirable. However, adding an external filter to suppress unwanted modes cause an undesirable increase in topology area. Recently, the ring resonators based the quarter-wave couplers with incorporate slow wave structures are use to eliminate the occurrence of the higher harmonics [6]. As mentioned above, the corrugations space between strip lines on the couplers are employed to equalise even- and odd-modes phase velocities in order to improve the coupler directivity that leads to introduce a zero in the frequency response of the coupled port at the second harmonic [7]. Further more, to reduce the circuit size and suppress the higher harmonics response, the embedded of stepped impedance transmission lines lowpass [8], or bandpass filters [9]-[11] into the ring resonator structures are feasible. Most of them were introduced the asymmetry structures into the ring resonators that leads a double-resonance in the frequency response of the ring with manifest themselves. In this paper, we proposed a design of resistive frequency doubler based on square ring resonator topology, which poses all these performances as shown in Fig 1. Section II presents the employing of inductively compensated parallel-coupled line to achieve the design, which is resulting in the suppression of frequencies response and reduction of the circuits' sizes as presented in Section III. The paper is finally concluded in Section IV.

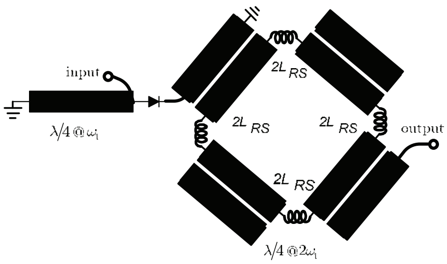


Fig. 1. The proposed resistive frequency doubler using inductive compensated square ring resonator as an output stage

2. Theory

2.1. Fundamental of Frequency Doubler

There are varieties ways to generate harmonics with passive devices. The dominant devices are resistive diode or schottky barrier diode [12]. Resistive multipliers with the schottky diode have one significant advantage, which is bandwidth broader than the others multipliers. Fig. 2(a), shows a simple resistive diode frequency doubler with parallel resonators at input and output frequencies. In this circuit, we assume that 1) the diode series resistance is very small and 2) the diode's capacitance can be absorbed in the capacitance of the resonators. The ideal parallel resonators are tuned to the fundamental and the second harmonic at input and output ports to provide open circuits at resonant and short circuits at all other frequencies [13]. Hence, the resonators short-circuit the diode at the unwanted harmonics, giving the best overall performance. In practically, parallel LC resonators can be replaced by any types of transmission line resonators or filters as shown in Fig. 2 (b),

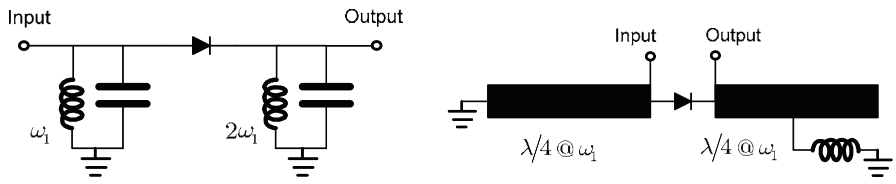
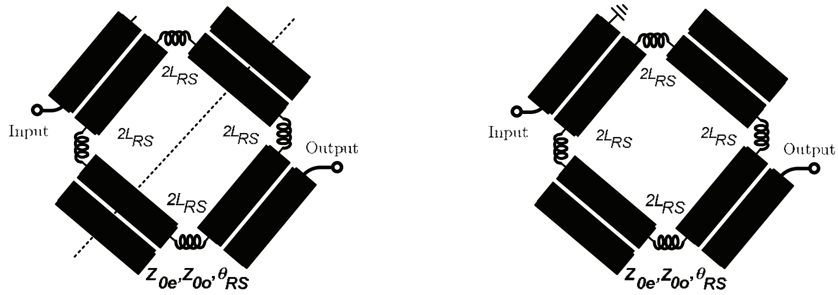


Fig. 2. Resistive diode frequency doubler with (a) LC and (b) microstrip line parallel resonator at input and output ports [13]



(a) (b)

Fig. 3. Schematic of the modified square ring resonator with singly shorted end coupled-feed to provide signal ground return path

which is consist of shottky barrier diode connecting with shorted-circuit quarter-wavelength transmission line at the operating frequency of f_0 at the input and the modified square ring resonator at the output ports to exhibit as the LC parallel resonators for frequencies f_0 and $2f_0$. In the multipliers, the resistive diode's junction capacitance should be low enough to be negligible at the output frequency and the circuit conversion loss is strongly depended on the diode series resistance. In the proposed circuit, the square ring resonator as shown in Fig. 3 (a) was modified by adding singly shorted end at input coupling-feed to provide signal ground return path as shown in Fig. 3(b). This resonator is used to replace the LC resonator at the output port. The compensated inductor (L_{RS}), which can implemented in either lumped or distributed forms and shortened electrical length of the coupler (θ_{RS}) use for adjusted so that 90$^{\mathrm{o}}$ phase difference between the direct (port 4) and coupled (port 2) ports ($\angle S_{41} - \angle S_{21}$) at centre frequency of f_0 is obtained are selected by [10], [11]:-

$$L_{RS} = \frac{1}{2\pi f_0} \operatorname{Im}\left(\frac{\left(Z_o^2 + Z_{0o}^2\right) Z_C - 2 Z_o Z_{0o} Z_{0e} \phi}{Z_o Z_C - Z_{0o} Z_{0e} \phi} \right) \tag{1}$$

where $\phi = \cosh\theta_e - \cosh\theta_o$ and $Z_C = j\left(Z_{0o}\sin\theta_e - Z_{0e}\sin\theta_o\right)$

Equation (1) offers a closed-form expression to design the compensating inductances for achieving high directivity at the centre frequency f_0 Similar to the other lumped compensation techniques, the centre frequency can be simply shifted back to original frequency by shortening the electrical length of the compensated parallel-coupled line to be:-

$$\theta_{RS} = \cot^{-1}\left(\frac{4\pi f_0 L_{RS} - Z_{oo}\cot\theta_o}{2 Z_{oe}} \right) \tag{2}$$

As already mentioned [10]-[11], with the shorted end coupling-feed structure, two zero transmission frequencies are occurred at both upper and lower stop band frequencies beside the transition band frequencies. In the proposed frequency doubler, the operating frequency of the resonator at the output port is designed at frequency $2f_0$ with the transmission response (S_{21}) around operating frequency would be preserved or minimal change from that of the square ring resonator without the adding singly shorted end coupled-feed.

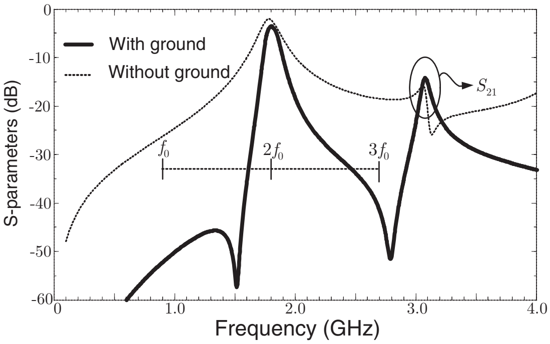


Fig. 4. Simulated results of the proposed square ring resonator with the singly shorted end coupled-feed

2.2. Square Ring Resonator with the Lumped Compensation Inductors

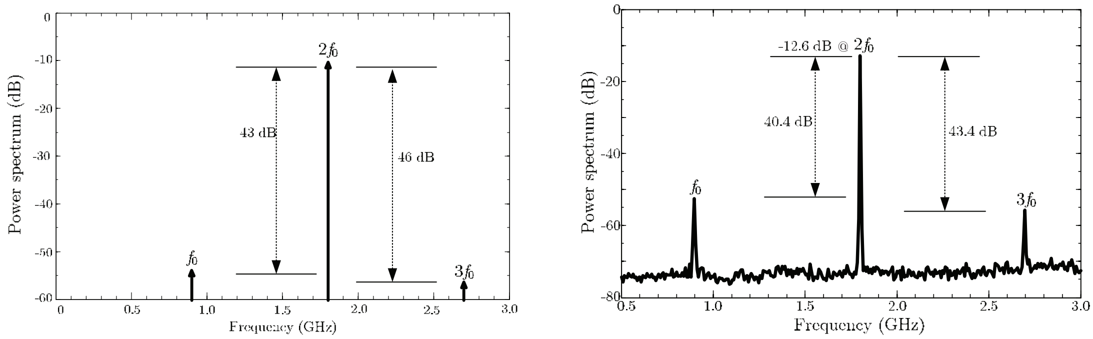
In this design topology, to enhance the spurious suppression performance at higher harmonics frequencies (especially for $2f_0$ and $3f_0$) of the proposed ring resonator. The uncompensated coupled lines were replaced by inductively compensated coupled lines. The transmission response around operating frequency (f_0) of the proposed resonator would be preserved or minimal change from that of the uncompensated ring resonator. The transmission phase with 0^o phase difference between input and output ports of the proposed ring resonator is also preserved. In the previous paper [5], a square ring resonator is constructed from four quarter-wavelength $(\lambda/4)$ coupled lines connected on all four sides. The resonator has symmetric structure with the disappearing of double-resonance. That mentioned square ring resonator has many attractive characteristics, which highly suits for wireless communication, these are low insertion loss, strong voltage coupling coefficient, high quality factor, wide stop band, and easy to design and implement. In this paper, present a modification of square ring resonator as described in [10], by using a loop of square ring resonator which is consisted of four inductive compensated coupled lines connected on all four sides as the previous paper. So, each couple of series inductors in each coupled lines junction can replaced by a single lumped or meander lines inductor of $2L_{RS}$. Two of the couplers are used to couple energy into and out of ring resonator with the opened end of the co-linear. Fig. 4 shows the simulated transmission of uncompensated and the proposed square ring resonators designed at 0.9 GHz. It is shown that the spurious responses at $2f_0$ and $3f_0$ harmonic frequencies are considerably reduced.

Table 1. Parameters of the designed frequency doubler circuit at input and output frequencies of 0.9/1.8 GHz

Techniques	Components	Coupler's length (θ,rad)	W,S,L (mm)
	$Z_{0e} = 70.84\ \Omega$	ε_{effe}	
	$Z_{0o} = 35.29\ \Omega$	ε_{effo}	
Inductive Comp.	2.8 nH	0.4π	2.4, 0.26,18.4

3. Design and Experimental Results

To enhance the proposed 0.9/1.8GHz input and output frequency doubler, a 1.8 GHz modified square ring resonator as shown in Fig. 1, is used to control the spurious suppression on the output port. The circuit prototype have been designed and fabricated on FR4 substrate with the following design parameters ε_r =4.55, h=1.6 mm and t=36um tanδ =0.02. In the prototype a square ring resonators was designed by using four sections of coupled lines with voltage coupling factor of 9.5 dB, which the odd- and even- modes characteristic impedances are Z_{0e}=70.84 Ω, Z_{0o}=35.29 Ω and effective even- and odd-mode permittivity ε_{effe},ε_{effo}, are 3.609 and 2.803, respectively. The shorted-circuit quarter-wavelength transmission line with characteristic impedances of Z_{0e}=60 Ω has been employed at input port to functionally as LC parallel resonator at 0.9 GHz. The single SGD102, GaAs C to X Band shottky barrier diode from Sanyo semiconductor have been used as the square law device.



(a) (b)

Fig. 5. Spectrum of the proposed frequency doubler (a) simulation, (b) measured

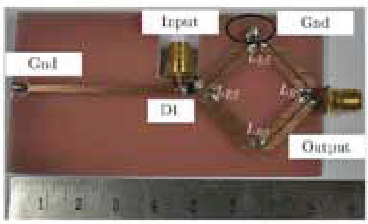


Fig. 6. PCB photographs of the proposed resistive frequency doubler

The physical design parameters of square ring resonator are W = 2.4 mm, S = 0.3 mm, L =18.2 mm. The compensated inductors for the designed resonator was calculated from (1), by using coupler's electrical parameters is 1.4 nH, therefore the total compensation inductors are 2.8 nH. The physical design parameters for Z_0=60 Ω shorted-circuit quarter-wavelength transmission line are W = 2.2 mm, and L =45 mm, as shown in Table II. In Fig. 5(a), the simulated result of the proposed frequency doubler shows the suppression performances at 0.9 GHz (f_0) and 2.7 GHz $(3f_0)$ below the desired frequency 1.8 GHz $(2f_0)$ more than 43 dB. The measurement was performed with HP8920B RF communication test set as signal generator and FSH3 spectrum analyzer from Rohde & Schwarz as shown in Fig. 5 (b), which is in good agreement with the simulated result. The implemented circuit presents the suppression performances at 0.9 GHz (f_0) and 2.7 GHz $(3f_0)$ below the desired frequency 1.8 GHz $(2f_0)$ more than 40 dB with the circuit's conversion loss 12.6 dB. The photograph of the PCB of the proposed frequency doubler based on square ring resonator is shown in Fig. 6. The circuit size excluding the input and output SMA connectors of the proposed frequency doubler is around 8.2×4.8 cm^2.

4. Conclusion

A novel square ring resonator with compensated lumped inductors has been proposed. The proposed topology have many attractive characteristics such as low insertion loss, strong voltage coupling coefficient, high quality factor, wide stop band, and easy to design and implement. The proposed implemented ring resonator size is reduced to more than 50% of the size of the conventional parallel-coupled ring resonator. The levels of spurious response at harmonics of the proposed square ring resonator are more than 26 and 22 dB at the 2nd and 3rd harmonics frequencies. The capability of the proposed square ring resonator has been proved by using for the efficiency enhancement of 0.9/1.8GHz frequency doublers. The implemented circuit shows the suppression performances at 0.9GHz and 2.7GHz below the desired frequency 1.8GHz more than 40dB with the circuit's conversion loss less than 12.6dB. It is believed that the proposed circuit can be simply modified to be microwave resonators or filters, which are suitable for various circuits in many modern wireless and microwave systems.

Acknowledgements

This work is financially supported by Faculty of Technology, and Institute of Research and Development, Udonthani Rajabhat University.

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